Investigation of cutting temperature and chip formation during rotational turning by multifaceted cutters

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Abstract. Effect of geometrical and technological parameters of method rotary turning by multifaceted cutters (RTMC) on the quality of machining was investigated. Using the numerical, analytical and experimental methods the effect of cutting conditions on roughness was determed. The resulting semi-empirical dependences allow to appoint the cutting conditions with predict roughness parameters Ra , Rz , $R_{\max}$.

1. Introduction

In the field of metal cutting of materials widely used such methods of turning as: the vertex cutting, peak less cutting, autorotation and forced rotary turning. Each of these methods has its rational application. However, these conventional machining methods have significant drawbacks in durability of the tool life, chips formation; the use of expensive MQL's cooling; the speed limitation, performance of machining and require the development of alternative and innovative methods of surface formation [1-3].

Rotary cutting reduces tool temperatures and the amount of tool wear owing interrupted turning, thermal diffusion into the tool body, and thermal dissipation into the air [4,5]. Tool rotation distributes the cutting heat and tool wear to the entire cutting edge with a constantly changing contact point, and consequently improves the tool life [6-8]. Tool-workpiece contact time, the length of the cutting edge, and cutting conditions have great influences on surface roughness, however, there has been few studies concerning these influences [6]. The kinematic parameters of the turning rotary process are the starting point for the selection of cutting conditions and tool geometry [8,9].

The RTMK method, developed at the Krasnoyarsk Polytechnic Institute of the Siberian Federal University, is one of the promising methods for processing such details as shafts from viscous, plastic and composite materials, as well as high-alloy, heat-resistant steel [8-10]. The method RTMC promising multi-faceted for extra-heavy-duty processing of difficult – to-cut materials, alloy, heat-resistant, hard-steels and alloys can be used in aerospace and transport engineering.

The objective of this study was to investigate effect of geometrical and technological parameters of RTMC on the quality of machining.

2. Results and Discussion

The parameters of chip geometry and workpiece roughness varies depend on the tool cutting edge (angles, tool geometry) and cutting conditions was determined by analytical and experimental methods. In the formation of the treated surface involves three movements: the main motion (rotation of the tool) V_r, linear motion or traverse f_n and additional moving of flow feed (workpiece rotation) f_{az}. The versatile cutter performs forced rotation around its axis with respect to the rotating speed V_r [8-10]. At the same time a tool is reported rectilinear motion along the axis of the workpiece longitudinal feed *fn*. Thus the tool rotation axis is set perpendicular to the axis of rotation of the workpiece and the center is on the axis line [10].

The rotary cutter is a multi-faceted plate of the cup shape with a bore hole and the cutting part, consisting from the N cutting blades [8-12]. Each blade comprises a front and rear surfaces which form between them a rectilinear cutting edge. Each blade cutting edge located in a plane perpendicular to the axis of rotation formed the multi-faceted cutters. The processing circuit of a multi-faceted rotary cutter shown in Fig. 1.

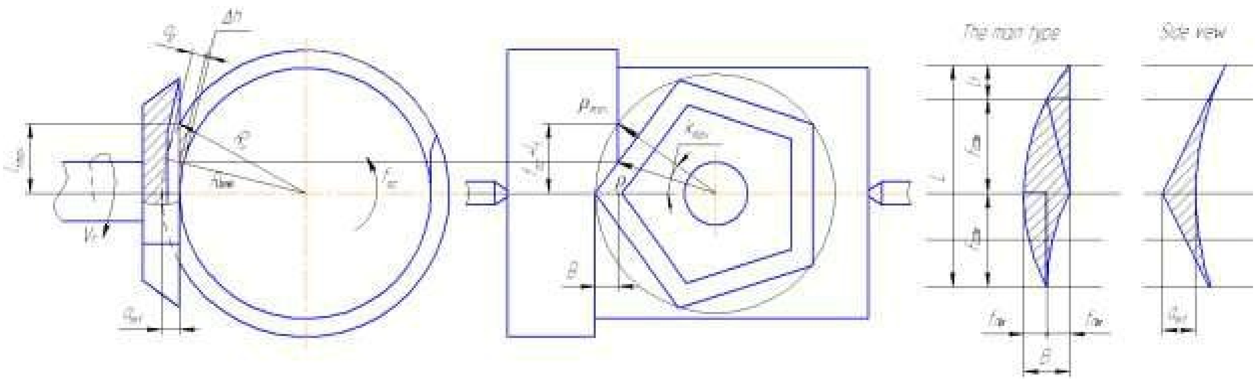

Figure 1. Kinematic scheme for determination the height of roughness (h)

The quality of the treated surface is estimated by the surface roughness and the state of the surface layer of the material. On Fig. 1 shows the estimated micro profile of cylindrical surface machined by RTMC. The height of surface irregularities determined by the formula:

$$\Delta h = \sqrt{\rho^2 \cdot \sin \kappa^2 + R_{\mathrm{dmin}}^2} + R_{\mathrm{dmin}}; \qquad (1)$$

where: ρ - radius vector of the cutting edge contour, mm; $R_{d\,\min}$ – the radius of machined workpiece, mm; k – the angle between the center axis and the contact point of the cutting edge and the machined surface.

Longitudinal feed on the cutter face of $f_{nbr} = B/2$. Longitudinal cutter feed on the treated turnover shaft is calculated using the formula $f_n = f_{nbr} \cdot n_r \cdot N / n_b$ (n_{r} - turning number of a workpiece, turn/min; n_{b} - turning number of the tool, turn/min; N - number of cutter profile faces.); The azimuthal feed to the edge of the tool is $f_{azbr} = \rho_{max} \cdot sin \kappa_{max}$ ($\rho_{\max}$ - maximum radius vector of the cutting edge contour, mm; $\rho_{\min}$ - minimum radius vector of the cutting edge contour, mm). The number of revolutions of the workpiece $n_b = f_{azbr} \cdot n_r \cdot N / \pi \cdot d_b$. The number of revolutions of the tool is determined by $n_r = \pi \cdot d_3 \cdot n_b / f_{azbr} \cdot N$.

In order to avoid the kinematic undulation ($l_{t\,\max}$) is necessary to appoint azimuthal feed (f_{azbr}) using the equations:

$$l_{t\max} = \sqrt{R_W^2 - (R_W - a_{mt})^2}; \qquad (2)$$

$$l_{t\max} \ge f_{az_{br}} + l_t \tag{3}$$

where: $l_{t\max}$ – height of exit the cutting blade from the cutting area under the plane of the centers, mm; R_W – the radius workpiece, mm.

The length (l_t) can be determined by the formula:

$$l_t = \sqrt{\rho_{\max}^2 - \left(\rho_{\max} - 2f_{n_{br}}\right)^2} - f_{az_{br}\max}\ ; \tag{4}$$

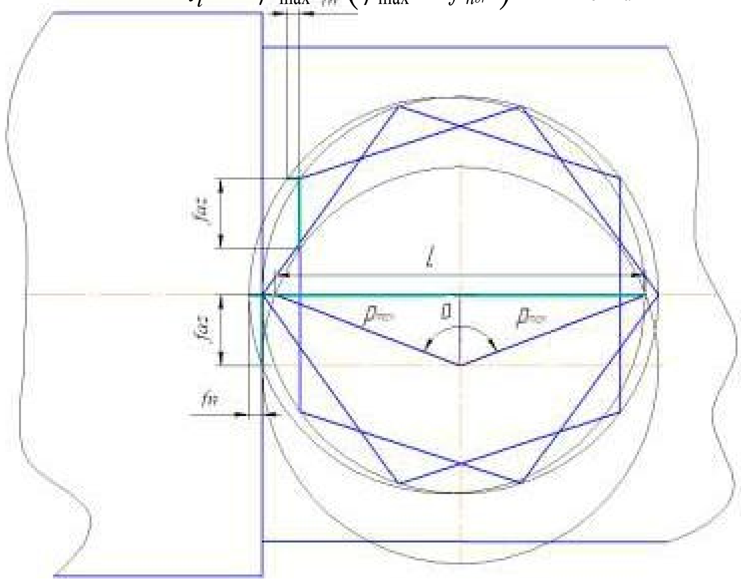

Figure 2. Scheme of destination feed

The azimuthal feed is assigned based on the following relationship:

$$f_{az\max} = \sqrt{\rho_{\max}^2 - \left(\rho_{\max} - f_n\right)^2} = \sqrt{2\rho_{\max}\cdot f_n - f_n^2}\ ; \tag{5}$$

With the known azimuthal feed is necessary to calculate a longitudinal feed, which is defined by the following equations:

$$f_{n\min} = \rho_{\max} - \sqrt{\rho_{\max}^2 - f_{az}^2} = \rho_{\max} - \frac{L}{2}\ ; \tag{6}$$

The chord L, can be determined by the formula:

$$L = 2\cdot\rho_{\max}\cdot\sin(\alpha/2); \tag{7}$$

The angle α is expressed as:

$$\cos(\alpha/2) = \frac{f_{az}}{\rho_{\max}}\ ; \tag{8}$$

Based on the formulas, it can be concluded that the rotation speed of the tool V_r should be at an order higher than the summary of the azimuthal feed f_{az} and longitudinal feed f_n.

Apart from the aforementioned main numerical and analytical methods, several experimental studies also investigate size effect of cutting conditions on surface roughness. Three roughness parameters, average roughness (Ra), mean peak-to-valley height (Rz), and maximum roughness (Rmax) by profilometer MarSurf M300 were used to evaluate the roughness. Choice of technological factor levels is carried out by means of single-factor experiment. The results presents on Fig 3.

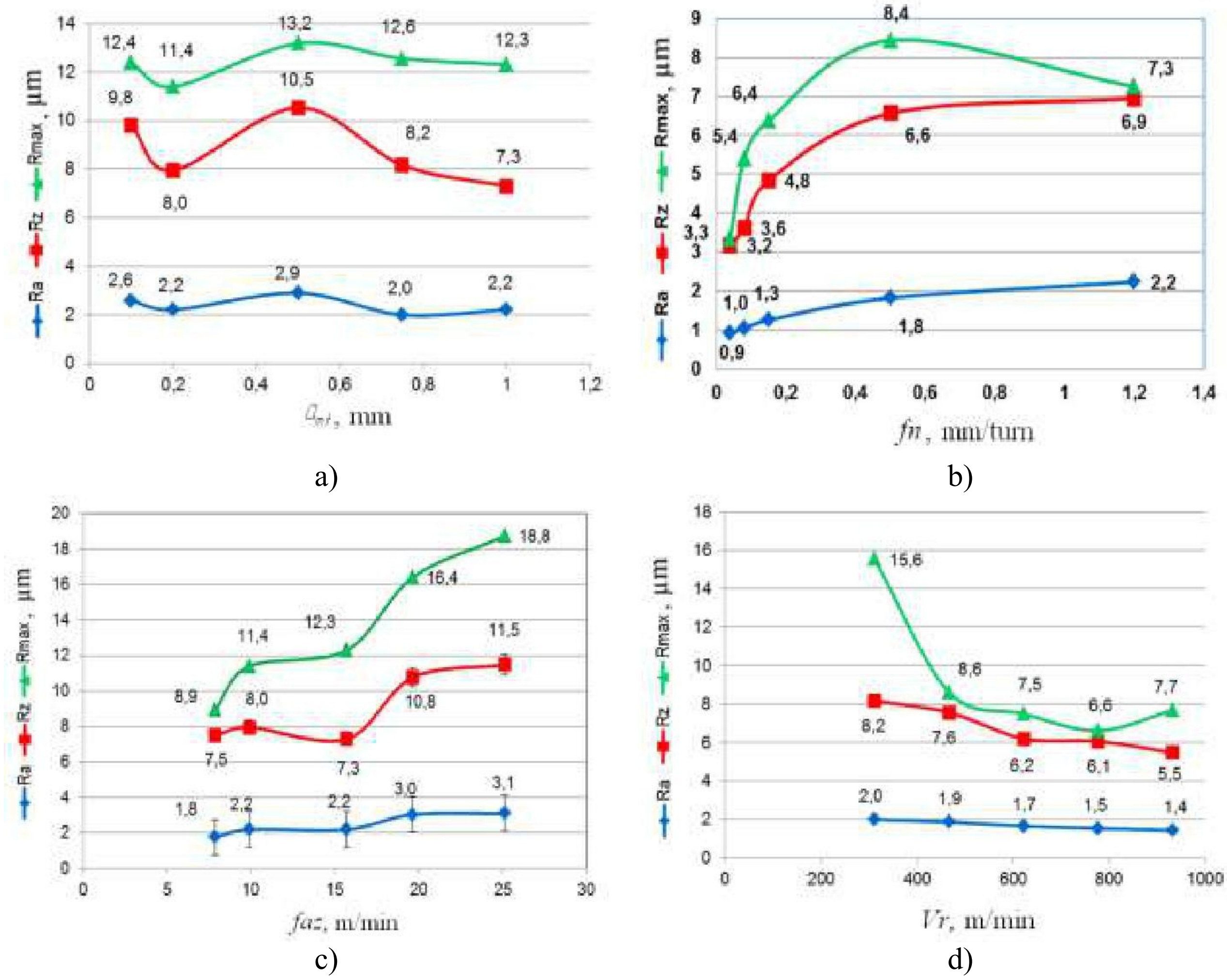

Figure 3. Effect of cutting conditions on surface roughness: a) – depth cutting a_{mf} b) – longitudinal feed f_n c) - azimuthal feed f_{az} d) – cutting speed V_r

Based on the analysis of single-factor experiments were selected varying levels of independent variables for the staging of the planned experiment f_n = 0.3 ... 1.2 mm / turn; f_{az} = 9.891 ... 19.625 m / min; V_r = 310 ... 621 m / min; a_{mf} = 0.3 ... 1.5 mm. Full factorial experiment planning matrix of type 2^4

Processing of experimental data allowed obtaining empirical equations between roughness parameters and cutting conditions (technological modes).

$$Ra = 6.01\,\frac{f_n^{0.2701}\cdot f_{az}^{0.4679}}{V_r^{0.3081}\cdot a_{mf}^{0.0548}}; \tag{9}$$

$$Rz = 41.52\,\frac{f_n^{0.2471}\cdot f_{az}^{0.3583}}{V_r^{0.3733}\cdot a_{mf}^{0.0721}}; \tag{10}$$

$$R\max = 251.89\,\frac{f_n^{0.2208}\cdot f_{az}^{0.594}\cdot a_{mf}^{0.02}}{V_r^{0.6775}}; \tag{11}$$

In order to determine the effect of each of the independent factors on surface roughness was carried out their ranking Fig. 4.

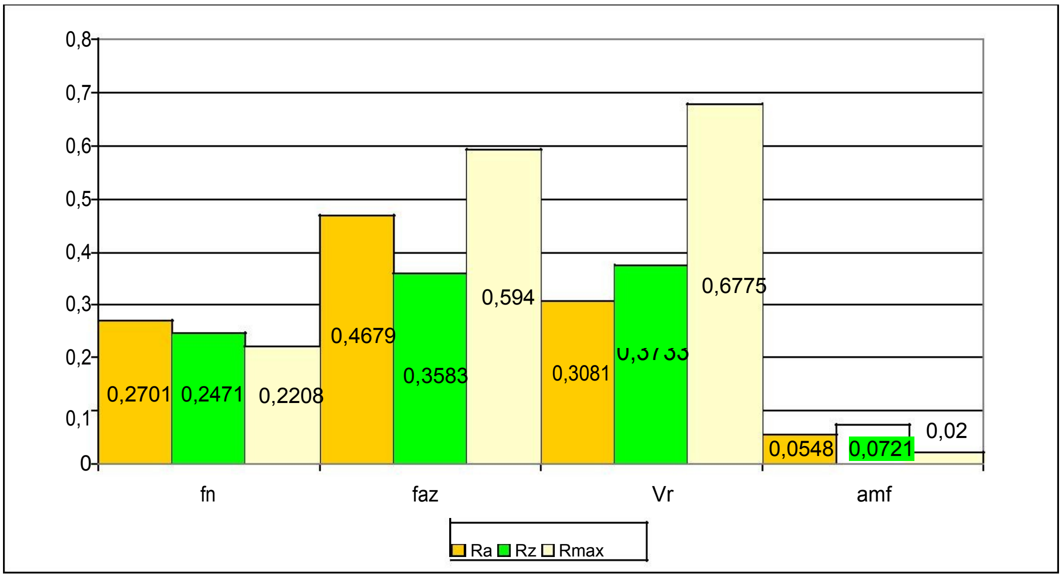

Figure 4. Effect of cutting conditions of RTMC on roughness parameters of machining surface.

Analysis rank chart shows that the dominant influence on the formation of high-altitude surface roughness parameters (Ra , Rz , $R_{\max}$) have azimuthal feed f_{az} and the speed of the main motion V_r. A cutting depth a_{mf} have no effect on surface roughness parameters.

Conclusion

Using different cutting edge geometry and the corresponding cutting depth a_{mf}, feeding f_n, azimuth feed f_{az}, cutting speed V_r, it is possible to reduce the contact time of the tool with the workpiece, as well as the frictional forces and the temperature of the tool.

Adhesions are also reduced utilizing the tool inclination angle control and MQL. Thus, our comprehensive theoretical estimates and experimental studies have established the nature of the influence of cutting conditions for RTMC on the roughness of the treated surface. The resulting semi-empirical dependences allow the appointment of the cutting conditions to predict roughness parameters Ra , Rz , $R_{\max}$ (set the cutting conditions with optimal "performance - quality of processing").

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